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TAGGING STUDIES AND DIVER OBSERVATIONS OF FISH POPULATIONS ON LIVE-BOTTOM REEFS OF THE U.S. SOUTHEASTERN COAST

R. O. Parker, Jr.

ABSTRACT

Tagging studies and visual observations of reef fishes were conducted off the southeast coast of the United States between 1972 and 1980 to determine population parameters independent of those obtained from fishery statistics. From 1972 to 1975, 4,150 reef fishes were tagged during 148 fishing trips off North Carolina, South Carolina, and Florida. Only 29 were recaptured. All recaptures were within 24 km of the tagging site. During 65 additional trips where 2,736 reef fishes were tagged during an intensive tagging study on a single reef off North Carolina from 1975 to 1977, 121 (4.4%) were recaptured. Only one tagged fish, a black sea bass, *Centropristis striata,* was caught away (9.7 km) from the tagging site. A mark-recapture, multiple census estimate of the black sea bass population was 33 times smaller than that made by SCUBA divers during the same period. Exploitation estimates of black sea bass indicated that they were underexploited in these waters in 1976. Eighty-seven species of reef fishes were observed by divers. Some of these species, such as red snapper, *Lutjanus campechanus,* and vermilion snapper, *Rhomboplites aurorubens,* apparently vacated the reef when the water temperature dropped below 16°C. Others, such as red porgy, *Pagrus pagrus,* white grunt, *Haemulon plumieri,* grouper, and juvenile vermilion snapper, apparently moved off the reef when the water temperature dropped below 11°C, only to return when temperatures warmed. Young-of-the-year fishes were observed on the reef between mid-May and mid-July when the bottom water temperature ranged from 20.5 to 27.0°C.

Reef fishes occur along the U.S. southeastern coast as far north as Cape Hatteras, North Carolina. Rock outcroppings and warm Gulf Stream water permit year-round occupancy of the outer continental shelf by many tropical and sub-tropical fishes (Huntsman, 1976; Miller and Richards, 1979; Parker and Ross, 1986).

Reef fishes contribute significantly to the economy of the southeastern states. Fishermen on 42 headboats operating off the southeastern coast (Cape Hatteras, North Carolina to Cape Canaveral, Florida) in 1982, captured over 1,144,000 kg of reef fishes during 164,072 angler days. (A headboat is a recreational fishing vessel that charges for a day's passage on a per person, thus per "head," basis.) At an average of $30.00 per fisherman per day, the fishery grossed close to five million dollars. In North Carolina alone there were eight headboats that landed over 287,000 kg of reef fishes during 27,000 days of fishing and grossed over $800,000. In addition, commercial landings of reef fishes in the southeast exceeded 2,513,346 kg with a value of $5,180,561.

This paper describes an extensive tagging study of reef fishes off North Carolina, South Carolina, and northern Florida between 1972 and 1975, and an intensive tagging study and visual observations on a small rock out-cropping in Onslow Bay, North Carolina from 1975 to 1977. The goal of these studies was to determine population parameters independent of those obtained from fishery statistics. In particular, we wanted to learn population sizes and movements of reef fishes important in the recreational and commercial fisheries so that potential yields could be estimated.

METHODS

Reef fishes were tagged extensively off North Carolina, South Carolina, and Florida from June 1972 to September 1975, and intensively on a small, 0.8 by 5.6 km, rock outcropping in Onslow Bay, North

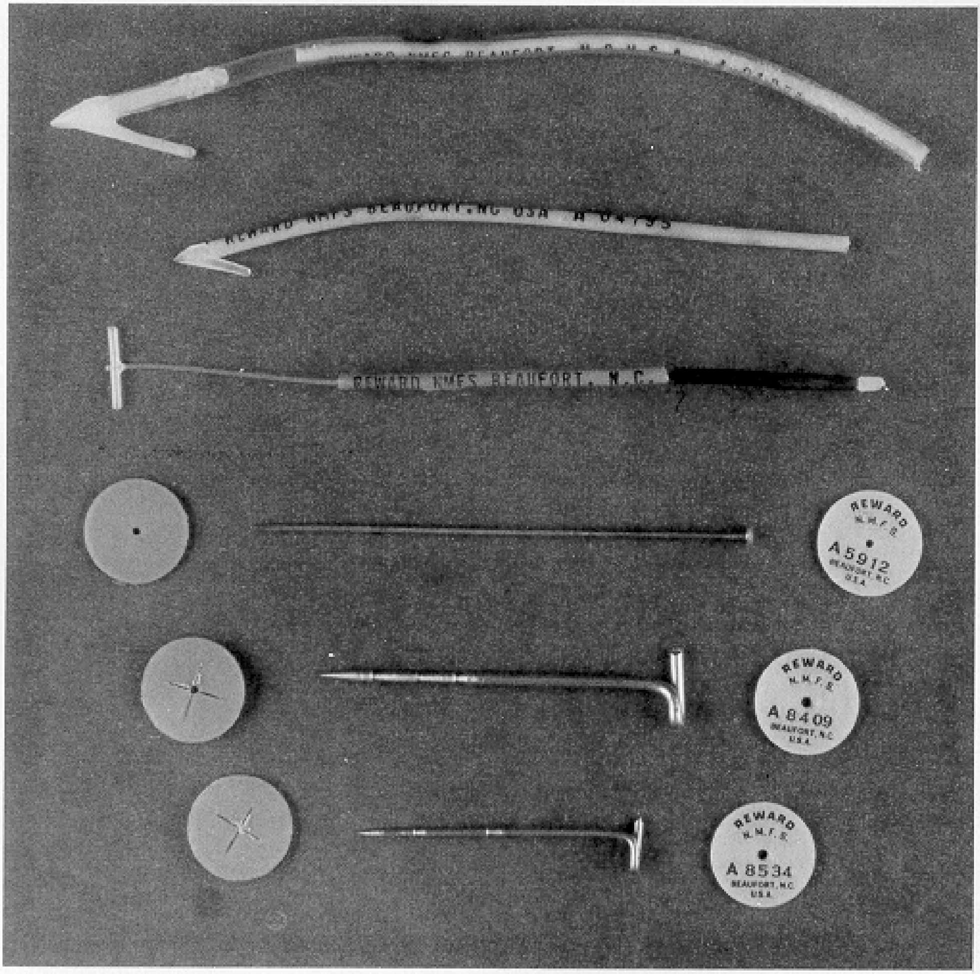

Figure 1. Tags used to tag reef fish (top to bottom): two sizes of Floy dart tags, Floy anchor tag, Peterson disc tag, and two sizes of modified disc tags (discs are 0.5 cm in diam).

Carolina from September 1975 to September 1977. The rock outcropping (34°14′N, 76°35′W) is 44 km south of Beaufort Inlet in 30 m of water, and is a typical inshore reef habitat with 4 m maximum relief and scattered areas overgrown with sponges, hydroids, and soft, and diminutive, hard corals. Fishes, caught by hook and line, were tagged from the R/V Onslow Bay, R/V Eastward, R/V Advance, commercial snapper vessels, and headboats. Four types of tags were used: Floy dart, Floy anchor, Peterson disc, and modified disc tags (Fig. 1). (The mention of trade names in this publication does not imply endorsement by the National Marine Fisheries Service). Tags were inserted through the body about 1 cm below the middle of the dorsal fin. Each tag had a legend "REWARD NMFS, Beaufort, NC. U.S.A." and a sequential number. Rewards were randomly allocated to tags such that 88% were \$1.00, 5% were \$5.00, 5% were \$10.00, and 2% were \$25.00 with an average tag value of \$2.13. The variable reward was designed to increase an angler's incentive to return tags (Wolff, 1972). Recaptures came from recreational and commercial fisheries using hook and line and, for black sea bass, traps.

We observed and counted fishes during 35 SCUBA dives between September 1975 and September 1977 at one location on the small rock outcropping in Onslow Bay, and counts were compared to population estimates derived during the intensive tagging study. Random station or transect selections were not practical because of an expected limited frequency of visits (because of adverse weather), limited bottom time (22 min allowing a 3 min safety margin), and a desire to determine seasonal abundance (requiring frequently monitoring the same station). Bohnsack and Bannerot (1986) and Thresher and Gunn (1986) concluded that better estimates of population densities were obtained from fixed sampling stations than from transect data, and Witzig (1988. Ph.D dissertation entitled Visual Assessment of Reeffish Communities, North Carolina State University, Zoology Department, 161 pp.) verified this hypothesis statistically by censusing known distributions of fish models. Underwater observations were continued through March of 1980, primarily to obtain more winter data (additional 16 dives). After locating the station on the reef crest, which was usually marked with surface and midwater buoys, we dove down and took a secchi disk (30 cm diam) reading near the anchor to measure lateral visibility. We then swam to the sampling site along a tagline from the buoy anchor and counted fishes important in the recreational and commercial fisheries in a 360° area. The actual counting area was a circle with a radius of 75% of the lateral visibility measurement because fishes lacked the contrasting colors of the black and white secchi disk and faded-out of view in the last quarter of the measurement. The fade-out distance was determined by observing fishes attacking white cloth markers on the measuring line. Fish counts were expanded to fish per hectare for comparison. We also recorded: time of day, bottom water temperature, fish behavior, and all species of fishes observed.

Results and Discussion

Extensive Tagging Study.—A total of 4,150 reef fishes were tagged during 148 fishing trips off North Carolina, South Carolina, and Florida from 1972 to 1975. Only 29 (0.7%) were recaptured. Tagging effort was impeded by weather, manpower, and vessel time. The low return rate resulted from an extremely small proportion of the populations tagged, a high rate of loss of dart tags, and unknown tagged fish mortality. Headboat landings, alone, in these areas during the period totaled approximately five million black sea bass, *Centropristis striata,* and over 2 million other fishes (Huntsman, 1976; pers. comm.). The proportion tagged becomes more minuscule when considering the numbers of reef fishes caught by commercial vessels, charter boats, and pleasure crafts.

Dart tags were used initially because they could be applied rapidly, thus minimizing the harmful effects of exposure on fish out of water. However, subsequent laboratory tag retention experiments in 1975 indicated a 75% loss of dart tags (from eight red porgy, *Pagrus pagrus*) but no loss of Peterson disc tags (three red porgy and 19 pinfish, *Lagodon rhomboides*) over 3 months. Fourteen of the pinfish lived and retained their tags another 3 months. The percentage of Peterson disc tagged fishes recovered to those released was 68% greater than that of the dart tagged fishes. Although we switched entirely to Peterson disc tags in 1975, 75% of the fishes tagged during the extensive tagging experiment were tagged with dart tags.

In addition to commercially manufactured tags, a pin and self-locking disc of our manufacture (Fig. 1) was designed and utilized. The stainless steel wire pin (1.6 mm diam) was stiff enough to push easily through the fish and had grooves into which a second disc would lock permitting rapid tag application. Retention in the field was believed to be excellent since eight tagged pinfish in a holding tank retained their tags for 3 to 7 months before dying of fin ulceration.

Tag returns indicated little movement. Seventeen of 19 red porgy were recovered less than 6 km from the tagging site. One fish at liberty for almost 2 years was recovered less than 2 km from the tagging site. The furthest movement was 24 km for two red porgy and one speckled hind, *Epinephelus drummondhayi.* The other nine fishes (three speckled hind, five scamp, *Mycteroperca phenax,* and one vermilion snapper, *Rhomboplites aurorubens*) were recovered less than 3 km from the tagging site.

Intensive Study.—To determine the number of fishes per unit of area of reef habitat as well as seasonality of species important in the recreational and commercial fisheries, all of our tagging effort was directed to one reef from September 1975

Table 1. Intensive tagging study (September 1975–September 1977)

Species	Tagged	Returned (%)	$\bar{x}$ days out	Max. days out
Black Sea Bass	1,325	100 (7.5)	92	474
Bank Sea Bass	248	11 (4.4)	51	134
Red Porgy	400	4 (1.0)	175	613
White Grunt	409	3 (0.7)	26	46
Vermilion Snapper	104	1 (1.0)	28	28
Red Snapper	7	0		
Gag	29	0		
Scamp	2	0		
Gray Triggerfish	70	2 (2.9)	133	254
Other	142	0		
Total	2,736	121 (4.4)		

to September 1977. During the same period divers made monthly counts of the fishes. Of 2,736 fishes, representing 40 species, tagged during 65 fishing trips, only 121 (4.4%, Table 1) were recaptured, one third by us. One tagged black sea bass was caught away from the reef. This fish was caught in April following a severe cold spell, 9.7 km closer to the shelf edge where the warm water of the Gulf Stream prevails throughout the year. Several black sea bass were recaptured as often as three times during the tagging study, and one gag, *Mycteroperca microlepis,* with an oddly pigmented head was seen by divers in the same area three times between May 1977 and October 1978. Lack of movement of black sea bass on artificial reefs in the South Atlantic Bight has been previously documented (Myatt, 1979; Parker et al., 1979; Ansley and Harris, 1981).

Only black sea bass were recaptured in sufficient numbers to permit population estimates (Table 1). Schnabel and Schumacher-Eschmeyer mark-recapture multiple census estimates were compared for the period of 5 February through 9 July 1976 when 25 tagged black sea bass were recaptured out of 703 releases. Although the Schumacher-Eschmeyer method accounts for a nonrandom distribution of tagged fish, for all practical purposes the two methods gave identical results, about 70 fish per hectare (Table 2).

Visual estimates of abundance of reef fishes important in the recreational and commercial fisheries were conducted during the same period. Generally, estimates varied inversely with visibility. When visibility was low (12 m or less) our estimates were high and vice versa (Fig. 2). We selected one of several high profile (2 to 4 m) rock outcrops that possessed an abundance of fishes as an index site. Fishes concentrated under and around the ledges during low visibility but not when the water was clear. Extrapolating density of fishes in a small visible area to fishes per hectare grossly overestimated abundance over the entire reef, which consisted mostly of low profile (<1 m) rock outcroppings sparsely inhabited by

Table 2. Population estimates of black sea bass on an 88 ha reef from tagging studies and visual counts (February 5–July 9, 1976)

Multiple census method	N	95% Limits	$Fish \cdot ha^{-1}$	$Kg \cdot ha^{-1}$
Schnabel	6,074	5,288–7,134	69	31
Schumacher-Eschmeyer	6,207	4,387–10,609	71	32
Visual	203,176	31,981–532,219	2,309	1,039

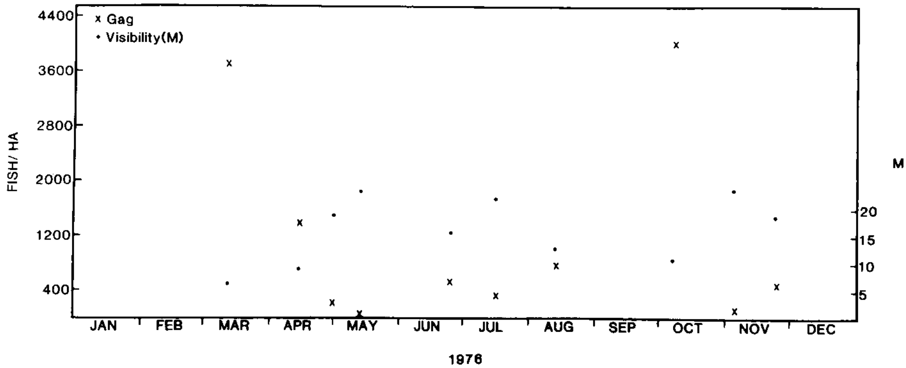

Figure 2. Visual estimates of abundance of gag compared to water clarity from March through November 1976.

fishes. Although the relationship of visibility to abundance confounded the determination of seasonality during 1976 and 1977 (2 of the 3 years for which we have the most data), a clearer picture emerged in 1978. Visibility remained high (≥ 13 m) from 31 May through 19 September and population estimates remained fairly constant for the species for which we have the most data: gag, black sea bass, and white grunt, *Haemulon plumieri* (Fig. 3A–C).

Mark-recapture and visual estimates of abundance of black sea bass were compared for the period of 5 February through 9 July 1976. Visual estimates were 33 times larger, but were characterized by a large confidence interval ($P = 0.95$) about the mean counts (Table 2). Further, there was large variability from month to month (3/12, 4/14, 5/13, 6/24) and within month (4/14, 4/30) (Fig. 4). Very large concentrations of black sea bass were seen in January 1977, perhaps in association with an offshore movement, then observed numbers decreased drastically in February as the water temperature fell from 13° to 7°C (Fig. 4). Water temperatures ranged from a high of 28.0°C in August 1978 to a low of 5.7°C in February, 1977 (Fig. 5). Generally, the bottom water temperature remained above 12°C. No red snapper, *Lutjanus campechanus,* or adult vermilion snapper were seen or caught when the bottom water temperature dropped below 16°C. Red porgy, white grunt, grouper, and juvenile vermilion snapper apparently left when the bottom water temperature dropped below 11°C. Most species of fishes occupied the reef throughout the year, but appeared to be less numerous during the winter months. This was probably caused, at least in part, by fishes burrowing during cold weather and reappearing when the water warmed. Only one black sea bass, two whitebone porgy, *Calamus leucosteus,* in stress coloration, and one dead blue angelfish, *Holacanthus bermudensis,* were seen on the reef 9 February 1977 when the water temperature was 5.7°C. Thirty-five days later 16 species were observed on the reef when the bottom water temperature was 13.8°C. This included 11 species (gag, black sea bass, bank sea bass, *Centropristis ocyurus,* belted sandfish, *Serranus subligarius,* red porgy, white grunt, cubbyu, *Equetus umbrosus,* spotted moray, *Gymnothorax moringa,* purple reeffish, *Chromis scotti,* bluehead, *Thalassoma bifasciatum,* and spotted goby, *Coryphopterus punctipectophorus*), seen 16 days prior to the cold spell when the water temperature was 15.2°C. It is highly unlikely that these species migrated to the Gulf Stream and returned during this period. I and others (T. H. Handsel and S. W. Ross, pers. comm.) have observed

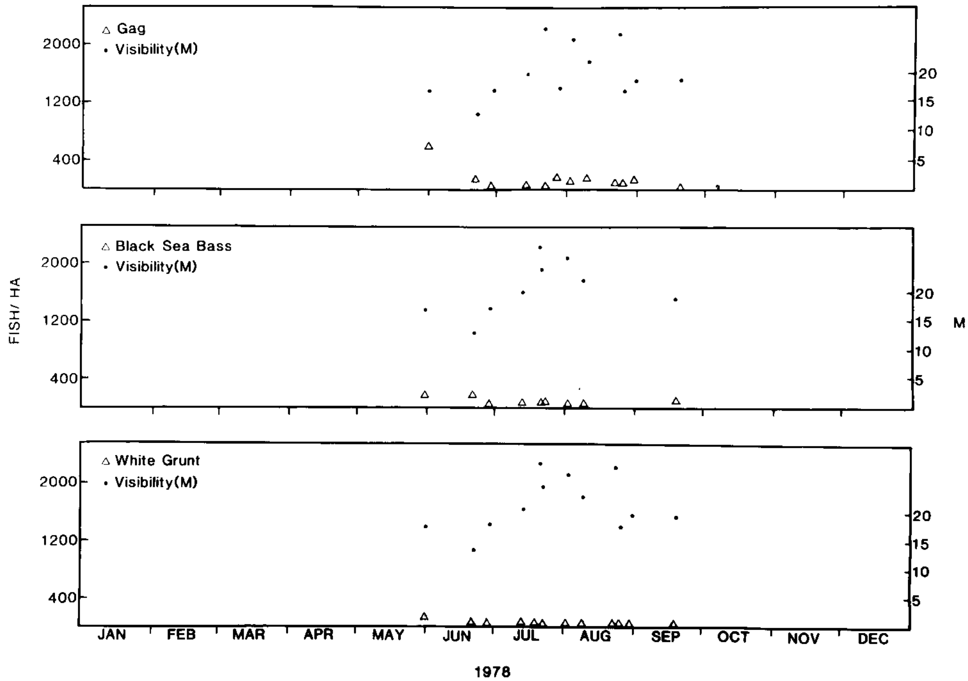

Figure 3A–C. Visual estimates of abundance of gag, black sea bass, and white grunt compared to water clarity from May through September 1978.

in home and laboratory aquaria, reef fishes (e.g., gag, black sea bass, bank sea bass) noncharacteristically burrowing in sediment. Perhaps some of the above species did the same during the cold spell, in addition to utilizing holes and deep crevices.

Of the 87 species observed by divers, the most frequently recorded were: gag, white grunt, black sea bass, bank sea bass, purple reeffish, *Chromis scotti,* belted sandfish, slippery dick, *Halichoeres bivittatus,* greater amberjack, *Seriola dumerili,* cubbyu, whitespotted soapfish, *Rypticus maculatus,* spottail pinfish, *Diplodus holbrooki,* and yellowtail reeffish, *Chromis enchrysurus* (Table 3). Small fishes and cryptic species were often overlooked by divers who were primarily interested in enumerating fishes important in the recreational and commercial fisheries.

Nearly transparent young-of-the-year fishes, <30 mm TL, were observed on seven occasions between mid-May and mid-July (Table 4), when bottom water temperature ranged from 20.5 to 27.0°C. Although no collections were made, the species appeared to be tomtate, *Haemulon aurolineatum,* spottail pinfish, purple reeffish, yellowtail reeffish, sea bass, and snapper.

Cleaning behavior was observed on three occasions. Gag were cleaned by a Spanish hogfish, *Bodianus rufus,* and a goby, *Gobisoma* sp., and a planehead filefish, *Monacanthus hispidus,* was cleaned by an unidentified goby.

Tagging Data versus Diver Observations.—Although tagging indicated little movement of reef fishes and provided an estimate of abundance of black sea bass, it gave no indication of the dynamics of reef populations observed by divers. The 51% of the 2,736 reef fishes tagged during the intensive study that were species other than black sea bass provided just 17% of the recaptures (Table 1). Only

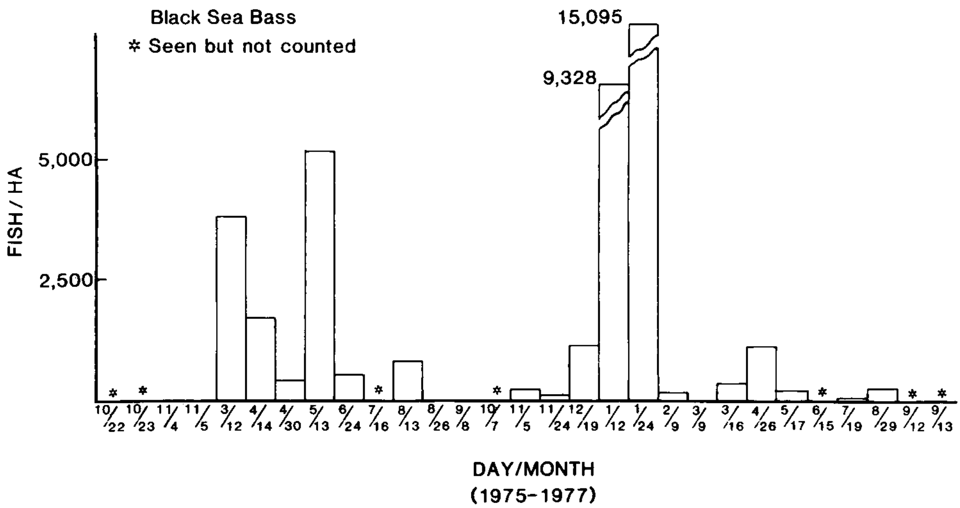

Figure 4. Population estimates of black sea bass, October 1975 through September 1977.

recaptures of black sea bass were sufficient for population estimates. Our estimate of 70 fish·ha^{-1} compares favorably with those of Wenner et al. (1986), 14 to 125 fish·ha^{-1}, off of South Carolina between 1981 and 1983, and with Powles and Barans' (1980) estimate of 51 fish·ha^{-1} from underwater television transects in the same area in 1976. Our visual estimates of abundance of black sea bass were 33 times larger. It appears that tagging data gave a more realistic estimate of density of black sea bass than did visual counts.

Divers, however, observed large fluctuations in abundance of black sea bass and other species important in the recreational and commercial fisheries. In addition to the large concentrations of black sea bass in January 1977 apparently associated with a mass offshore movement, divers counted 40 red snapper and 50 gag on 23 October 1975 and 110, 88, and 100 gag on 5 November 1975, 7 October 1976, and 14 February 1980. Omitting these sightings, average counts

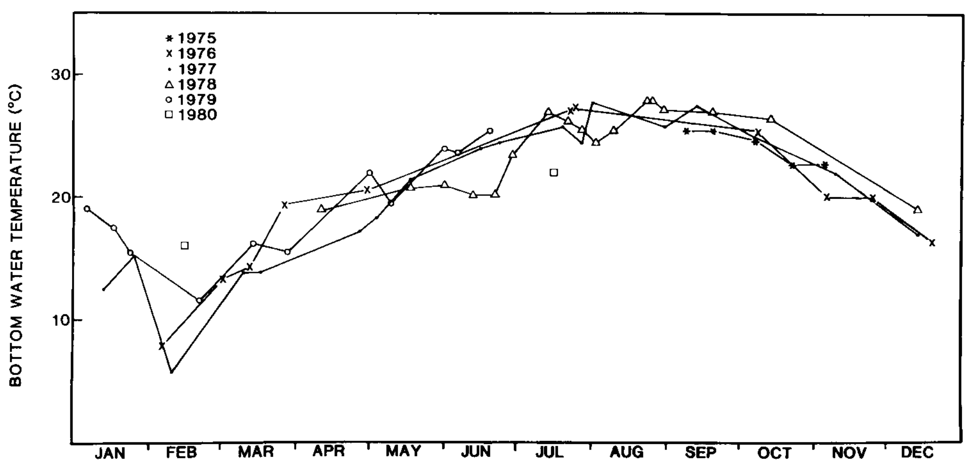

Figure 5. Bottom water temperature, September 1975 through July 1980.

Table 3. Number of dives (51 total) during which fishes were observed from September 1975 through March 1980

Orectolobidae	
Ginglyostoma cirratum, nurse shark	2
Odontaspididae	
Odontaspis taurus, sand tiger	1
Carcharhinidae	
Rhizoprionodon terraenovae, Atlantic sharpnose shark	5
Galeocerdo cuvieri, tiger shark	1
Caracharhinus leucas, bull shark	1
Sphyrnidae	
Sphyrna sp., hammerhead	1
Dasyatidae	
Dasyatis sp., stingary	3
Muraenidae	
Gymnothorax moringa, spotted moray	5
G. saxicola, blackedge moray	1
Muraena retifera, reticulate moray	5
Congriidae	
Conger sp. or *Paraconger caudilimbatus*, conger eel	3
Clupeidae	
Sardinella aurita, Spanish sardine	2
Lophiidae	
Lophius americanus, goosefish	1
Gadidae	
Urophycis earlli, Carolina hake	9
Serranidae	
Mycteroperca microlepis, gag*	51
M. phenax, scamp	22
Epinephelus morio, red grouper*	3
Centropristis striata, black sea bass*	48
C. ocyurus, bank sea bass*	48
Diplectrum formosum, sand perch	4
Serranus subligarius, belted sandfish	45
S. tigrinus, harlequin bass	2
Liopropoma eukrines, wrasse bass	11
Grammistidae	
Rypticus maculatus, whitespotted soapfish	38
Apogonidae	
Apogon pseudomaculatus, twospot cardinalfish	24
Carangidae	
Serila dumerili, greater amberjack*	41
S. rivoliana, almaco jack*	7
Caranx crysos, blue runner	4
C. ruber, bar jack	2
Decapterus punctatus, round scad	26
Lutjanidae	
Lutjanus campechanus, red snapper*	20
Rhomboplites aurorubens, vermilion snapper*	7

Table 3. Continued

Haemulidae	
Haemulon plumieri, white grunt*	50
H. aurolineatum, tomtate*	30
Sparidae	
Pagrus pagrus, red porgy*	30
Calamus leucosteus, whitebone porgy*	27
C. nodosus, knobbed porgy*	15
Diplodus holbrooki, spottail pinfish*	38
Stenotomus caprinus, longspine porgy	8
Archosargus probatocephalus, sheepshead	2
Scianidae	
Equetus umbrosus, cubbyu	41
E. lanceolatus, jacknife-fish	5
E. punctatus, spotted drum	2
Mullidae	
Pseudupeneus maculatus, spotted goatfish	1
Mulloidichthys martinicus, yellow goatfish	1
Kyphosidae	
Kyphosus sp., chub	2
Ephippidae	
Chaetodipterus faber, Atlantic spadefish	6
Chaetodontidae	
Chaetodon ocellatus, spotfin butterflyfish	9
C. sedentarius, reef butterflyfish	1
C. striatus, banded butterflyfish	1
Pomacanthidae	
Holacanthus bermudensis, blue angelfish	16
H. ciliaris, queen angelfish	2
Pomacentridae	
Chromis multilineatus, brown chromis	1
C. insolatus, sunshinefish	1
C. scotti, purple reeffish	48
C. cyaneus, blue chromis	3
C. enchrysurus, yellowtail reeffish	37
Poacentrus partitus, bicolor damselfish	19
P. variabilis, cocoa damselfish	21
P. fuscus, dusky damselfish	3
Microspathodon chrysurus, yellowtail damselfish	3
Labridae	
Halichoeres bivittatus, slippery dick	43
H. garnoti, yellowhead wrasse	9
H. caudalis, painted wrasse	4
Bodianus pulchellus, spotfin hogfish	10
B. rufus, Spanish hogfish	17
Thalassoma bifasciatum, bluehead	8
Tautoga onitis, tautog*	18
Sphyraenidae	
Sphyraena barracuda, great barracuda	11
Blenniidae	
Parablennius marmoreus, seaweed blenny	24
Hypleurochilus geminatus, crested blenny	2

Table 3. Continued

Gobiidae	
Gobiosoma xanthiprora, yellowprow goby	3
Coryphopterus puntipectophorus, spotted goby	13
Ioglossus calliurus, blue goby	13
Acanthuridae	
Acanthurus bahianus, ocean surgeon	3
A. coeruleus, blue tang	2
A. chirurgus, doctorfish	2
Scombridae	
Scomberomorus cavalla, king mackerel*	10
Euthynnus alletteratus, little tunny*	3
Scorpaenidae	
Scorpaena dispar, hunchback scorpionfish	1
Balistidae	
Balistes capriscus, gray triggerfish*	22
Monacanthus hispidus, planehead filefish	28
Tetraodontidae	
Sphoeroides spengleri, bandtail puffer	3
S. maculatus, northern puffer	2
Canthigaster rostrata, sharpnose puffer	1
Diodontidae	
Diodon sp., porcupinefish	2
Molidae	
Mola mola, ocean sunfish	2

* Target species.

were less than one red snapper and 10 gag per dive. Only four red snapper and four gag were caught by hook and line on 23 October, and just one gag each on 5 November and 7 October; no fishing was done on 14 February.

Although more frequent sampling was prohibited by rough weather, it is apparent that continued tagging effort would provide information mostly on black sea bass. Other species, such as: red porgy, white grunt, and gag, although present in large numbers, could not be readily caught.

Black Sea Bass Exploitation and Potential Yield.—If we expand our estimate of black sea bass density from the tagging study (70 fish$\cdot$ha^{-1}) to the entire area surveyed based on the estimated amount of black sea bass habitat [944,300 ha (Parker et al., 1983)], there were about 66 million harvestable fish in 1976. The headboat catch of black sea bass that year was 287,705 kg (R. L. Dixon and G. R. Huntsman. Unpublished manuscript. Catches and fishing effort of the United States South Atlantic Headboat Fleet, 1972–1982.) or about 639 thousand fish, and the commercial catch was 207,900 kg (US National Marine Fisheries Service, 1976) or about 462 thousand fish. Converting weight to numbers of fish using mean weight of black sea bass landed in the headboat fishery, we estimated that together the headboat and commercial catches made up about 1.7% of the standing stock. This estimate of exploitation agrees with an estimate of annual exploitation rate of 0.026 calculated from length frequencies by Huntsman and Witzig (Unpublished manuscript. Mortality rates of some reef fishes of the U.S. South Atlantic.) using Low's 1981 estimate of natural instantaneous mortality of 0.30. The

Table 4. Young-of-the-year fishes observed between June 1976 and July 1978

Date	Tomtate	Spottail pinfish	Purple reeffish	Yellowtail reeffish	Sea bass	Snapper	Other	Bottom temp (°C)
6/24/76						1,000's		Unknown
5/17/77		1,000's		2				21.5
5/17/78							1,000's	20.8
5/31/78	100's		100's		100's			21.0
6/12/78			50+					20.3
6/21/78			24+	1				20.8
7/13/78			24+	6				27.0

concurrence of absolute values of exploitation suggests that exploitation of black sea bass, and probably most reef species, was very low prior to the late 1970's. Indeed Gulland's (1971) simplistic and consequently suspect, method of estimating potential sustained yield from virgin biomass indicates that a sustained harvest of 10 million black sea bass, nine times greater than that harvested, was possible.

Further pursuit of the implications of the exploitation estimate leads to fascinating, but troublesome questions about the population dynamics of black sea bass. While these questions are beyond the scope of this paper, they deserve mention so that readers are alerted both to problems in application of our results and to potential areas of significant research. Based on my estimate of the exploitation rate, u, it appears that while landings and total mortality (Z) nearly doubled from 1976 to 1981, thereafter Z continued to rise to 1.1 while landings returned to 1976 levels (Table 5).

Alternative, and equally hard to accept, explanations for this behavior of catch and mortality rates are that (1) yield per recruit ($Y \cdot R^{-1}$) increased 3.3 times, from 37.3 to 124, while the population (N) decreased to one third of its 1976 value or (2) that either considerable recruitment occurred from outside the fishing area or that the fishery shifted its effort to a black sea bass reservoir outside the usual fishing area or (3) that $F \cdot Z^{-1}$ is biased. The first explanation requires belief in an extraordinary change in the $Y \cdot R^{-1}$ regime, while the first half of the second explanation requires, contrary to results of several tagging studies (previously cited), that black sea bass undertake substantial movements. The third explanation implies that small changes in either fishing mortality rate (F) or natural mortality rate (M) can occur without changing Z much, such that large changes in total catch weight (C_w) result without large changes in $Y \cdot R^{-1}$. For example, in 1981, given no change in N or M, F would only change from 0.03 (1976) to 0.09 and $Y \cdot R^{-1}$ would increase from 37.3 to 56.6. This could account for the large change in total catch. Intensive examination of current knowledge of black sea bass biology and

Table 5. Estimated population parameters of black sea bass off the U.S. southeastern coast from fishery data

Year	C_w $\times 10^8$	$\bar{W}$	C_n $\times 10^6$	M	F	Z	F/Z	Y/R	U	N $\times 10^6$
1976	4.95	410	1.20	0.30	0.03	0.33	0.09	37.30	0.03	46.90
1981	8.92	240	3.70	0.30	0.32	0.62	0.52	124.00	0.24	15.60
1986	5.56	250	2.20	0.30	0.80	1.10	0.73	181.80	0.49	4.50

Symbols: All symbols are defined in text except $\bar{W}$ = mean weight (gm) of fish; C_n = estimated catch in numbers.

increased attention to at-sea study of black sea bass population sizes and movements are needed to resolve these anomalies.

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Address: *NOAA, National Marine Fisheries Service, Southeast Fisheries Center, Beaufort Laboratory, Beaufort, North Carolina 28516-9722.*